SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT I, Tomoyuki Akiyama, a citizen of Japan residing at Kawasaki, Japan have invented certain new and useful improvements in

OPTICAL TIME-DIVISION MULTIPLEX SIGNAL PROCESSING APPARATUS AND METHOD, OPTICAL TIME-DIVISION MULTIPLEX SIGNAL RECEIVER

of which the following is a specification : -

TITLE OF THE INVENTION

OPTICAL TIME-DIVISION MULTIPLEX SIGNAL PROCESSING APPARATUS AND METHOD, OPTICAL TIME-DIVISION MULTIPLEX SIGNAL RECEIVER

CROSS-REFERENCE TO RELATED APPLICATION

The present application is based on Japanese priority application No.2000-371918 filed on December 6, 2000, the entire contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

The present invention generally relates to optical signal processing apparatuses and especially to an optical time-division multiplex signal processing apparatus.

Optical time-division multiplexing technology is an indispensable art in today's super-fast optical telecommunication system in addition to the technology of wavelength-multiplexing.

In the optical time-division multiplexing technology, signal components of channels are sampled with different timings. By superposing the signal components thus sampled, a multiplexed optical signal is formed. As a result, it becomes possible to transmit optical signals of plural channels through a single optical fiber.

In the technology of optical time-division multiplexing, the speed of incoming optical time-division multiplex signals is generally much higher than the response speed of a photodiode or other high-speed optical detectors. Because of this, it is practiced to first separate the incoming optical time-division multiplex signal supplied to a receiver into optical signal components of respective channels by using an electro-optic modulator and then detect the optical signal components thus separated by a

photodiode.

Figure 1 shows an example of a conventional optical time-division multiplex signal receiver 10.

Referring to Figure 1, an optical time-division multiplex signal OTDM transmitted through an optical fiber 11 is supplied to an electro-optic modulator 12. The electro-optic modulator 12 is further supplied with a clock voltage signal corresponding to a desired channel from a clock signal source 13 and changes the transmittance thereof in response to the clock voltage signal. As a result, the optical sampling is achieved in the electro-optic modulator 12 with respect to the incoming optical time-division multiplex signal with the timing provided by the clock voltage signal, and an optical signal component for a specified channel is extracted. The optical signal component thus extracted is then supplied to a photodiode 14 through an optical fiber or an optical waveguide for conversion to an electric signal.

Figure 2 shows the construction of another optical time-division multiplex signal receiver 20.

Referring to Figure 2, an optical time-division multiplex signal OTDM transmitted through an optical fiber 21 is supplied to an all-optical gate 23, wherein the all-optical gate 23 is supplied with an optical clock signal via an optical waveguide 22 and changes a transmittance thereof in response to the optical clock signal. As a result, the optical signal component of the channel corresponding to the optical clock signal is extracted and is outputted to an optical waveguide 24 formed at an output side of the all-optical gate 23. The optical signal component thus extracted is detected by a photodiode 25.

However, in the construction of Figure 1, there exists a drawback in that, while the response speed of the electro-optic modulator 12 is faster than

the response speed of a photodiode, there is a limit and the advantage may be lost in the case the transmission rate of the optical time-division multiplex signal is increased further in future.

In the construction of Figure 2, the all-optical gate 23 has a response speed sufficient for responding to a high-speed optical time-division multiplex signal. However, such an all-optical gate 23, relying upon the optical-absorption-saturation phenomenon caused by an optical clock signal, requires a strong optical clock signal for on-off driving, and there arises a problem in that a large and bulky construction is necessary.

SUMMARY OF THE INVENTION

Accordingly, it is a general object of the present invention to provide a novel and useful optical time-division multiplex signal processing apparatus wherein the foregoing problems are eliminated.

Another and more specific object of the present invention is to provide an optical time-division multiplex signal processing apparatus capable of extracting optical signal components of respective channels from a high-speed optical time-division multiplex signal with simple construction.

Another object of the present invention is to provide an optical time-division multiplex signal processing apparatus, comprising:

an optical dispersion part supplied with an optical time-division multiplex signal and an optical clock signal, said optical dispersion part providing optical dispersion to said optical time-division multiplex signal and said optical clock signal;

an optical detector coupled optically to said optical dispersion part, said optical detector detecting said optical time-division multiplex signal

and said clock signal from said optical dispersion part in a superposed state; and

a filter connected to an output terminal of said optical detector, said filter filtering out an electric signal of a desired frequency band from an output electric signal of said optical detector.

According to the present invention, the optical time-division multiplex signal and optical clock signal are provided with a chirp by the optical dispersion part. As a result, each of the optical time-division multiplex signal and the optical clock signal undergoes a change of spectrum such that the wavelength changes with time. Thus, each of the optical signals is changed into an optical signal having a waveform that continues for some time as a result of the chirp, even in the case the incoming optical signal is a very short optical impulse. The optical signals each provided with a chirp as such are superimposed with each other in the present invention, and as a result, there is caused a beat, as a result of interference between the optical time-division multiplex signal and the optical clock signal, with a frequency corresponding to the timing difference between the optical time-division multiplex signal and the optical clock signal. Thus, by detecting the beat by using an optical detector and by taking out a desired frequency band by using a filter, it becomes possible to extract the signal component of a desired channel from the optical time-division multiplex signal.

Thus, according to the present invention, it becomes possible to provide a signal processing apparatus that separates the high-speed optical time-division multiplex signal into respective channels by a very simple construction.

Other objects and further features of the present invention will become apparent from the

following detailed description when read in conjunction with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagram showing the construction of an optical time-division multiplex signal receiver according to a related art;

Figure 2 is a diagram showing the construction of an optical time-division multiplex signal receiver according to another related art;

Figure 3 is a diagram showing the construction of an optical time-division multiplex signal receiver according to a first embodiment of the present invention;

Figure 4 is a diagram explaining the operational principle of the optical time-division multiplex signal receiver of Figure 3;

Figures 5A and 5B are diagrams explaining result of an experiment conducted with regard to the optical time-division multiplex signal receiver of Figure 3;

Figure 6 is another diagram explaining the experiment regarding to the optical time-division multiplex signal receiver of Figure 3;

Figure 7 is a further diagram explaining the experiment regarding the optical time-division multiplex signal receiver of Figure 3;

Figure 8 is a further diagram explaining the experiment regarding the optical time-division multiplex signal receiver of Figure 3;

Figure 9 is a further diagram explaining the experiment regarding the optical time-division multiplex signal receiver of Figure 3;

Figure 10 is a diagram showing the construction of an output electric signal used in the optical time-division multiplex signal receiver of Figure 3;

Figure 11 is a diagram showing a modification of the optical time-division multiplex signal receiver of Figure 3;

Figure 12 is a diagram showing the construction of an optical time-division multiplex signal receiver according to a second embodiment of the present invention;

Figure 13 is a diagram showing the construction of the a multi-channel optical time-division multiplex signal receiver according to a third embodiment of the present invention;

Figure 14 is a diagram showing the band-pass characteristics used in a demodulator circuit in the receiver of Figure 13;

Figure 15 is a diagram showing the construction of a multi-channel optical time-division multiplex signal receiver according to a fourth embodiment of the present invention;

Figure 16 is a diagram showing the band-pass characteristics are used in a demodulator circuit in the receiver of Figure 15; and

Figure 17 is a diagram showing the construction of an optical delay element used in the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[FIRST EMBODIMENT]

Figure 3 is a diagram showing the construction of a receiver 30 of an optical time-division multiplex signal according to a first embodiment of the present invention, while Figure 4 explains the operational principle of the receiver 30.

Referring to Figure 3, the receiver 30 has a construction in which an optical fiber 31 guiding an incoming optical time-division multiplex signal OTDM and an optical fiber 32 guiding an optical clock signal CLK are connected optically with each other in

an optical coupler 33, and thus, the time-division multiplex signal and optical clock signal CLK are superposed in the optical coupler 33. The optical signal thus formed as a result of the superposition is then injected from the optical coupler 33 into a dispersion medium 34, which may be formed of an optical fiber loop. As represented in (a) and (b) of Figure 3, the optical time-division multiplex signal OTDM and also the optical clock signal CLK are formed of an optical pulse train. As will be explained in detail with reference to Figure 4, the optical pulses forming the optical time-division multiplex signal OTDM or the optical clock signal CLK undergoes a dispersion in the dispersion medium 34, and there is formed a chirp in the optical time-division multiplex signal OTDM and the optical clock signal CLK as they are transmitted along the dispersion medium 34.

The optical time-division multiplex signal OTDM and the optical clock signal CLK thus provided with a chirp are then converted to an electric signal in a photodiode 35. Further, by using a demodulator circuit 36 that includes a filter therein, a signal component of desired channel is extracted from the output electric signal of the photodiode 35, as represented in (c) of Figure 3.

Next, Figure 4 is referred to.

In (b) of Figure 4, it can be seen that the optical signal pulses of the channels 1 - 4 are repeated consecutively in the optical time-division multiplex signal OTDM and are transmitted along the optical fiber 31 to form a pulse train, wherein each optical signal pulse has a widely spread frequency spectrum pertinent to an impulse. Further, the optical clock signal CLK in optical fiber 32 also has a widely spread frequency spectrum as shown in (a) of Figure 4. In (a) and (b) of Figure 4, it should be noted that the vertical axis represents the frequency while the

horizontal axis represents the time. The optical time-division multiplex signal OTDM and optical clock signal CLK are superposed with each other in an optical coupler 33. Thus, the optical signals that are injected into the dispersion medium 34 from the optical coupler 33 has a spectrum in which the time-division multiplex signals OTDM and the optical clock signals CLK are superposed as represented in (c) of Figure 4. In the illustrated example, the timing of optical clock signal CLK is slightly behind the timing of the optical signal pulse for the channel 1.

The optical signals thus entered into the dispersion medium 34 experience a dispersion as explained previously, and the spectrum of the optical signals is changed to a characteristic spectrum including a chirp as represented in (d) of Figure 4. In (d) of Figure 4, it can be seen that there is caused a change of frequency from low frequency to high frequency with time in correspondence to the chirp. In the optical signal including such a chirp, the optical signal pulse and the optical clock signal pulse CLK of the channels 1 - 4 exist simultaneously at an arbitrary time, and accordingly, there is caused a beat as a result of interference of these signals.

For example, it can be seen in Figure 4 that there exists a generally constant frequency difference Δf between the optical pulse spectrum for the channel 1 and the optical pulse spectrum for the optical clock CLK due to the fact that both the optical time-division multiplex signal OTDM and the optical clock signal CLK experience the same chirp in the same dispersion medium 34. As a result, the optical signal that exits from the dispersion medium 34 includes the beat signal of the beat frequency Δf as shown in (e) of Figure 4. As the beat signal of the beat frequency Δf is formed as a result of interference between the optical signal component for the channel 1 and the

optical clock, the beat signal maintains the information transmitted over the channel 1.

Thus, it becomes possible to detect the beat signal of the beat frequency Δf in the form of electric signal by detecting the exit optical signal of the dispersion medium 34 by a photodiode 35 as shown in (e) of Figure 4. Furthermore, there appear, at the output terminal of the photodiode 35, beat signals formed as a result of interference between the optical signal components for the channels 2 - 4 and the optical clock CLK or as a result of mutual interference between the optical signal components of the channels 1 - 4. These additional beat signal components have a higher beat frequency than the beat frequency Δf.

Thus, by extracting the beat signal of the beat frequency Δf from the output signal of the photodiode 35 by using an appropriate filtering circuit, it becomes possible to reproduce the information that was transmitted through the channel 1. Thereby, the photodiode 35 has a sufficient response speed for signal detection, as the photodiode 35 is used to detect the beat signal of the frequency Δf, not the high-speed optical time-division multiplex signal OTDM itself.

Figure 5A shows the construction of the optical signal processing apparatus used for verifying the possibility of the optical time-division multiplex signal processing apparatus 30 of Figure 3, wherein those parts of Figure 5A corresponding to the parts described previously with Figure 3 are designated by the same reference numerals and the description thereof is omitted.

Referring to Figure 5A, an optical pulse oscillator 31A is provided at an input end of the optical fiber 32, and the optical pulse oscillator 31A injects optical pulses having a pulse width of about

300fs (femtoseconds) into the optical fiber 32 with a frequency of 80MHz.

In the optical fiber 32, there is provided an optical delay element 31B and a polarization controller 31C between the optical pulse oscillator 31A and the optical coupler 33, and the optical pulses produced by the optical pulse oscillator 31A are provided with a delay time by the optical delay element 31B and a polarization plane by the polarization controller 31C. After being provided with the delay time and the polarization plane by the optical delay element 31B and the polarization controller 31C as noted above, the optical pulses are injected into the single-mode optical fiber loop 34 used as a the dispersion medium via the optical coupler 33. It should be noted that the polarization controller 31C is formed of a quarter-wavelength retardation plate $31C_1$ and a half-wavelength retardation plate $31C_2$ aligned on an optic axis as represented in Figure 5B. Thus, the plane of polarization of an incoming optical can be controlled by rotating the polarization controller 31C about the optical axis in the case that an incident optical beam has been entered. In the construction of Figure 5A, an ordinary single-mode optical fiber having a length of 1 km is used for the single-mode optical fiber loop 34. Such a single mode optical fiber may be the one having a zero dispersion at the wavelength 1.3μm band and a maximum dispersion of 10ps/km at the wavelength of 1.55μm band.

Meanwhile, the output optical pulse of the optical pulse oscillator 31 A is branched by a coupler 31D provided between the optical delay element 31B and the optical pulse oscillator 31 A. The optical pulse thus branched is then converted to an optical pulse train having an interval of about 2.5ps by an optical multiple reflection element 31E in which a half mirror

and a prism are combined. In the construction of Figure 5, the optical pulse train thus formed is injected to the optical fiber 31 as an optical multiplex signal substituting the optical time-division multiplex signal OTDM.

Figure 17 shows an example of the optical delay element 31B.

Referring to Figure 17, the optical delay element 31B includes a lens $31B_1$ coupled to the input-side optical fiber 31d extending from the optical coupler 31D and a lens $31B_2$ coupled to an optical fiber 31c that extends to the polarization controller 31C. Further, right-angle prisms $31B_3$ and $31B_4$ are disposed between the lens $31B_1$ and the lens $31B_2$ in such a manner that the distance between the prism $31B_3$ and the prism $31B_4$ is variable. Thus, the optical beam supplied along the optical fiber 31d is reflected toward the right angle prism $31B_4$ at a first mirror surface of the right angle prism $31B_3$, while the right angle prism $31B_4$ reflects in turn the optical beam that has come in from the right angle prism $31B_3$ consecutively by the two right-angle mirror surfaces, such that the optical beam returns to the right angle prism $31B_3$. The optical beam thus returned to the right angle prism $31B_3$ is reflected by another, second mirror surface perpendicular to the foregoing first mirror surface and is injected to the output-side optical fiber 31c via the lens $31B_2$. By changing the distance between prisms $31B_3$ and $31B_4$ in optical delay element 31B, it is possible to cause a desired optical delay.

Figure 6 shows the waveform obtained for the case in which an optical pulse having an initial pulse half-height width of 300fs, formed by the optical pulse oscillator 31 A, is caused to pass through the optical fiber 34.

Referring to Figure 6, it can be seen that

the optical pulse has a pulse half-height width of about 270ps, indicating that there actually occurred a substantial optical dispersion in the optical fiber 34.

Figure 7 shows the result of analysis of the output electric signal of the photodiode 35 by using a spectrum analyzer.

Referring to Figure 7, it can be seen that there appears a spectral peak in the output electric signal of the photodiode 35 in the vicinity of 0GHz in each of the optical pulses transmitted over the optical fiber 34. In Figure 7, it can be seen that there exists also a different spectral peak in the vicinity of 9GHz. It should be noted that this additional spectral peak corresponds to the beat signal of the beat frequency Δf that is formed between the signal optical pulses injected into the optical fiber 31 and the optical clock pulses injected into the optical fiber 32.

Thus, in the construction of Figure 5A, there occurs an increase of the beat frequency Δf when the delay time caused by the optic delay element 31B is increased, and the beat signal shifts to the side of higher frequency in the representation of Figure 7. When delay time is decreased, on the other hand, the beat frequency Δf is decreased, the beat signal shifts to the side of lower frequency. Naturally, when the delay time is set to zero, the spectral peak of the beat signal overlaps with the spectral peak of optical pulse itself in Figure 7.

Further, Figure 8 shows the output electric signal of the photodiode 35 corresponding to the beat frequency component of 7GHz for the case the delay time of the optic delay element 31B is changed variously in the construction of Figure 5A.

Referring to Figure 8, the first peak pair observed in the vicinity of the delay time of 3ps corresponds to the beat between the first optical

pulse of the OTDM signal from the optical fiber 31 and the optical clock pulse from the optical fiber 32. It can be seen that there appear two peaks in the output electric signal of the photodiode 35 respectively in correspondence to the case in which the timing of the optical clock pulse is in advance with respect to the timing of the OTDM signal pulse and in correspondence to the case in which the timing of the optical clock pulse is behind the timing of the OTDM signal pulse. The peak pair that follows the foregoing peak pair corresponds to the beat between the second OTDM signal pulse and the optical clock pulse. A similar relationship holds also for the third and fourth peak pairs.

Thus, it was demonstrated that it is possible to form a beat signal between the incoming optical time-division multiplex signal OTDM and the optical clock signal by using the construction of Figure 3 and that the detection of such a beat signal is possible by the construction of Figure 3.

Figure 9 shows the waveform of the signal component of the channel 1 obtained by filtering the output voltage signal of the photodiode 35 by the filter 36A in the demodulation circuit of Figure 10. By detecting the output voltage signal by using an envelop detector 36B, it is possible to reproduce the information of the channel 1.

Figure 11 shows a modification of the receiver 30 of Figure 3.

In the construction of Figure 11, a polarization eliminator device 32 A is provided for eliminating polarization from the optical clock signal CLK injected into the optical fiber 32. The polarization eliminator device 32 A may be provided to the output end of optical coupler 33.

[SECOND EMBODIMENT]

Figure 12 shows the construction of a receiver 40 of optical time-division multiplex signals according to a second embodiment of the present invention, wherein those parts corresponding to the parts described previously are designated by the same reference numerals and the description thereof will be omitted.

Referring to Figure 12, an optical time-division multiplex signal OTDM enters into a first dispersion medium 34A formed of a single-mode optical fiber in the reception device 40 of this embodiment, and an optical clock signal CLK enters into a second dispersion medium 34B of also a single-mode optical fiber. The optical fibers 34A and 34B are coupled optically with each other in the optical coupler 33, and the optical time-division multiplex signal OTDM and the optical clock signal CLK are superposed in the optical coupler 33 and supplied to the photodiode 35 for optical-electric conversion.

Furthermore, the output electric signal of the photodiode 35 is processed by the demodulator circuit 36 shown in Figure 10, and the information of desired channel is reproduced in the form of electric signal.

Thus, the optical time-division multiplex signal OTDM and the optical clock signal CLK are provided with a chirp by causing a dispersion in the respective dispersion media 34A and 34B. By using a medium having substantially the same dispersion characteristic for the dispersion media 34 A and 34B, an operation similar to the receiver 30 of Figure 3 can be realized.

[THIRD EMBODIMENT]

Figure 13 shows the construction of a multi-channel optical time-division multiplex signal receiver 50 according to a third embodiment of the

present invention, wherein those parts of Figure 13, corresponding to the parts described previously are designated by the same reference numerals and the description thereof will be omitted.

Referring to Figure 13, an optical coupler 34a is provided at the output side of the dispersion medium 34A, and the optical time-division multiplex signal OTDM that has passed through the dispersion medium 34A is branched to plural optical waveguides 34_1 - 34_n, wherein each of the optical waveguides 34_1 - 34_n extends to a corresponding one of the optical couplers 33_1 - 33_n.

Each of the optical couplers 33_1 - 33_n, is coupled optically with the dispersion medium 34B, and the optical time-division multiplex signal OTDM having a chirp is superposed with the optical clock signal CLK also having a chirp in each of the optical couplers 33_1 - 33_n.

The optical signal thus formed is then forwarded from the optical couplers 331 - 33n to the corresponding photodiodes 35_1 - 35_n for conversion to electric signals.

The output electric signals of the photodiodes 35_1 - 35_n are then processed by the output electric signals 36_1 - 36_n. Thus, the beat signal components corresponding to the desired channels Ch_1 - Ch_n are extracted by filtering out the output electric signals 36_1 - 36_n individually, and the output electric signals thus filtered out are then subjected to an envelop detection process.

Figure 14 shows the characteristic of a filter that is used with output electric signals 36_1 - 36_n for separating the signals of respective channels in the construction of Figure 13.

As can be understood from Figure 14, filters having different pass-bands are provided in the demodulation circuits 36_1 - 36_n. Thus, it becomes

possible to extract a beat signal between the optical signal component and the optical clock signal CLK for any arbitrary optional channels Ch_1 - Ch_n as explained previously with reference to (e) of Figure 4.

[FOURTH EMBODIMENT]

Figure 15 shows the construction of a multi-channel optical time-division multiplex signal receiver 60 according to a fourth embodiment of the present invention, wherein those parts of Figure 15 explained previously are designated by the same reference numerals and the description thereof will be omitted.

Referring to Figure 15, optical delay elements $34b_1$, $34b_2$, … $34b_n$ are provided between the dispersion medium 34B and optical coupler 33_1, between the dispersion medium 34B and optical coupler 33_2, …, between the dispersion medium 34B and the optical coupler 33_n in the reception device 60, respectively, wherein the optical delay element $34b_1$ has a delay time τ_1 determined so as to form a beat signal of 7GHz band, for example, between the optical signal component for the channel Ch_1 in the optical time-division multiplex signal OTDM and optical clock signal CLK. Similarly, the optical delay element $34b_2$ has a delay time τ_2 determined so as to provide a beat signal of 7GHz band between the optical signal component of the channel CH_2 in optical time-division multiplex signal OTDM and the optical clock signal CLK. Further, the optical delay element $34b_n$ has a delay time τ_n determined such that a beat signal of 7GHz band is formed between the optical signal component of the channel CH_n in the optical time-division multiplex signal OTDM and the optical clock signal CLK.

In the receiver 60 of such construction, it becomes possible to reproduce the optical signal of each channel in the optical time-division multiplex

signal OTDM by filtering the output electric signal of the photodiodes 35_1 - 35_n in the cooperating demodulation circuits 36_1 - 36_n with substantially the same pass-band frequency corresponding to the beat frequency.

In the construction of Figure 15, it should be noted that the demodulation circuits 36_1 - 36_n process the signals of the same frequency band such as 7GHz. Thus, the demand for response speed imposed to the photodiodes 35_1 - 35_n is relaxed substantially as compared with the construction of Figure 13.

In each of the aforementioned embodiments, it should be noted that the dispersion media 34, 34A and 34B are not limited to a single mode optical fiber loop but a prism or diffraction grating can be used for this purpose.

Further, the present invention is not limited to those embodiments described heretofore, but various variations and modifications may be made without departing from the scope of the invention.